

# **Sensors for Measuring the Volume Scattering Function of Oceanic Waters**

## **FINAL REPORT**

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# **SENSORS FOR MEASURING THE VOLUME SCATTERING FUNCTION OF OCEANIC WATERS**

## **FINAL REPORT**

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## **LONG-TERM GOAL**

Characterizing the volume scattering function (VSF) of oceanic waters still remains one of the most outstanding problems in optical oceanography. The goal of this program is to advance significantly our knowledge of the VSF of oceanic waters, particularly coastal waters. To achieve this goal we will develop new VSF instruments that will be capable of accurately and routinely measuring *in situ* profiles of the complete VSF.

## **OBJECTIVES**

Our scientific objective is to measure, *in situ*, the volume scattering function concomitant with other optical property measurements and the particle size distribution in a wide variety of oceanic waters. Since we already have at hand a number of instruments and methods for measuring the absorption, beam attenuation, and backward-scattering coefficients, the VSF measurement will provide the only missing link to definitively testing instrument closure. By means of closure we will be able to precisely document the accuracy of our optical property measurements. A related objective is investigate the accuracy of using Mie theory to compute the VSF based on the particle size distribution and index of refraction (which is usually inferred). In general we will apply our VSF measurements to a wide variety of modeling problems in optical oceanography. Our technological objective is to develop accurate, *in-situ* profiling instruments that can measure the VSF over the range of scattering angles from 0.1 to 170 degrees.

## **APPROACH**

The existing data [Petzold, 1972] show that the VSF's of marine particles typically increase by four orders of magnitude as the scattering angle goes from 90 to 1 degree, and they increase by another two orders of magnitude from 1 to 0.1 degrees. This presents great difficulty in measuring the VSF, requiring exceptionally high angular resolution and dynamic range in the electro-optics of an ocean VSF meter. At larger scattering angles (approximately 30 to 170 degrees), the relative intensity of light scattered into a narrow solid angle is exceedingly small, so that highly sensitive, yet low noise photodetection is required. In addition, any *in-situ* VSF meter must be able to withstand the harsh ocean environment, staying radiometrically and electronically stable

to maintain its calibration and accuracy. Finally, there is the important issue of accurately calibrating the instrument, which requires careful analysis of the electro-optic response of the sensor and appropriate measurements to properly characterize the light propagation through the system. Our approach to addressing this difficult instrument development project will make use of the unique optical and electronic technology and calibration techniques we developed to solve the problems we faced in building instruments for measuring light scattering in the ocean [Maffione and Honey, 1992; Maffione and Dana, 1996; 1997].

Analytical modeling is the first step we take in developing a new design for an ocean optical instrument. This step consists of developing the initial optical layout and the equations that describe the transfer of radiant power through the system. The equations must also describe the propagation of radiant power through the sample volume of water. In the analytical design and modeling phase, the single-scattering approximation is used for this part of the problem. Usually these equations have to be inverted as part of the instrument calibration, and thus IOP instruments are almost always designed to minimize the detection of multiple scattering. When multiple scattering is unavoidable, it can be effectively treated using the concept of quasi-inherent optical properties, which is usually important to long-pathlength systems [Maffione and Dana, 1996]. To completely characterize and understand the optical response of the VSF sensor, we will employ a Monte Carlo (MC) model. The MC model will simulate photon propagation from the point where the collimated source enters the sample water volume to where the scattered light reaches the window or aperture of the detector. Any combination of the water's absorption and scattering properties can be entered into the model, so that the instrument's response to various types of oceanic waters can be explored.

The electro-optic design is a critical part in the development of an ocean-optical instrument. Not only must the optical and mechanical aspects of an instrument be carefully designed so that the instrument operates properly in the harsh oceanic environment, but so must the electronics. Often in fact, the demands placed on the electronics are much greater than those placed on the optics. In addition to the environmental problems that have to be resolved, there is the more basic problem of designing an electro-optic system that can accurately detect low levels of light with high dynamic range, often with the added complication of high ambient light that must be rejected in the detection. In general, any compact and robust ocean-optical instrument requires a highly specialized, state-of-the-art electro-optic design. While the basic principles of electro-optic detectors are simple and widely understood, numerous subtle, lesser-known engineering factors come into play in designs of the type we propose. The factors involved also change depending on the specific measurement. Scattering measurements, which involve extremely small optical signals over the general angles, require the utmost attention to the noise generated by each component in the receiver circuitry. Forward scattering measurements have inherently higher signal levels, easing noise requirements, but require extreme stability over time and temperature changes. While each measurement requires careful attention to every detail of the circuit design,

they involve very different priorities and tradeoffs. We will apply techniques we have developed and refined over the course of several previous generations of scattering instruments to the present problem [Maffione and Honey, 1992; Maffione and Dana, 1996; 1997].

## **WORK COMPLETED**

The first year of this project was a small pilot effort to develop a working design for the VSF sensor. We have completed the design and identified all components and electro-optic circuits needed for the sensor, which we are calling HydroBeta. HydroBeta will have the following specifications:

1. Both the forward angle (0.1 to 3 degrees) and general angle (10 to 170 degrees) measurements are integrated into one instrument.
2. Measurements are made at 17 discrete general angles, from 10 to 170 degrees, in 10 degree increments.
3. Forward-angle measurements include 10 angles which cover the range from 0.1 to 3 degrees.
4. The VSF at the 27 measured angles are all measured nearly simultaneously (to within a millisecond), which allows the instrument to continuously profile the VSF of the water column. Furthermore, the "noise" spectrum of turbulent fluctuations can be resolved, which may be especially important for the near-forward-angle scattering.
5. The scattering volume is undisturbed, so that both the inherent turbulence of the sampled water volume and aggregated particles within it are preserved.
6. Each of the 17 general angle measurements is performed with separate optical receivers that are optimized both electronically and optically for the particular angle being measured.
7. The forward-angle receiver consists of a "bullseye" detector comprising 10 concentric rings, each of which is an independent photodetector with its own amplifier circuitry optimized for the signal level for that scattering angle. This design also obviates the need for interchangeable field stops, an undesirable feature of previous forward-angle systems.
8. The light source is an interchangeable miniature laser producing a well-defined ( $TEM_{00}$  mode) Gaussian beam with a very narrow spectral bandwidth. Several lasers of this type are commercially available, including solid-state Nd:YAG (532

nm) and tunable laser diodes (635 to 840 nm). Also, soon to appear on the market will be laser diodes that operate in the blue-green part of the spectrum.

## RESULTS

Because this project has just begun and is currently in the design phase, there are no results yet to report.

## IMPACT/APPLICATIONS

We expect that the impact of our measurements of the complete VSF will have an enormous impact on nearly all areas of optical oceanography. No measurements of the kind we plan to obtain have ever been made. Indeed, the nearest data of this type were obtained over 25 years ago [Petzold, 1972]. This lack of systematic and complete VSF measurements has greatly hampered our understanding of light scattering by marine particles, the testing and refinement of optical models, and the calibration of ocean-optical systems.

## TRANSITIONS

This project has just begun and thus there are not yet any transitions. However, we certainly expect that our VSF measurements and instruments will be used on many basic and applied programs involving oceanic optics.

## RELATED PROJECTS

This project is closely related to the author's ONR funded program, "Optical Closure in Coastal Waters." The new VSF instrument will be a key component to testing optical closure. In addition, HydroBeta will be an important water-column instrument on ONR's CoBOP program. This project is also related to an SBIR program, funded by NAWC, to develop a commercial forward-scattering meter. The technology we are developing on this basic research program is being applied to the commercial program.

## REFERENCES

Maffione, R.A., and R.C. Honey, 1992. Instrument for measuring the volume scattering function in the backward direction, *Ocean Optics XI*, G. D. Gilbert, Editor, Proc. SPIE, 1750, 15-26.

Maffione, R.A., and D.R. Dana, 1996. *In-situ* characterization of optical backscattering and attenuation for lidar applications, Selected Papers on, *Lidar Remote Sensing of Natural Waters: from Theory to Practice*, V Feigels and Y. Kopilevich, Editors, SPIE, 2964, 152-163.

Maffione, R.A., and D.R. Dana 1997. Instruments and methods for measuring the backward-scattering coefficient of ocean waters, *Appl. Opt.*, **36**, 6057-6067.

Petzold, T. J., 1972. Volume scattering functions for selected ocean waters, *SIO Ref.* 72-28, 79 pages.